ATLAS/ICESat-2 L3A Inland Water Surface Height, Version 3

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

Jasinski, M. F., J. D. Stoll, D. Hancock, J. Robbins, J. Nattala, J. Morison, B. M. Jones, M. E. Ondrusek, T. M. Pavelsky, C. Parrish, and the ICESat-2 Science Team. 2020. *ATLAS/ICESat-2 L3A Inland Water Surface Height, Version 3*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ATLAS/ATL13.003. [Date Accessed].

FOR QUESTIONS ABOUT THESE DATA, CONTACT NSIDC@NSIDC.ORG

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL13

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION

1.1 Parameters

Along-track water surface heights for inland water bodies plus statistics. Water bodies include lakes, reservoirs, bays, estuaries, and rivers, plus a 7 km, near-shore buffer. Water surface heights are provided as both height above the WGS 84 ellipsoid (ITRF2014 Reference Frame) and height above the Earth Gravitational Model 2008 (EGM2008) mean sea level (MSL). Statistics include along-track surface slope (where data permit), mean and standard deviation, subsurface 532 nm attenuation, wave height, and coarse depth to bottom topography.

1.2 File Information

1.2.1 Format

Data are provided as HDF5 formatted files. HDF is a data model, library, and file format designed specifically for storing and managing data. For more information about HDF, visit the HDF Support Portal.

The HDF Group provides tools for working with HDF5 formatted data. HDFView is free software that allows users to view and edit HDF formatted data files. In addition, the HDF - EOS | Tools and Information Center web page contains code examples in Python (pyhdf/h5py), NCL, MATLAB, and IDL for accessing and visualizing ICESat-2 files.

1.2.2 ATLAS/ICESat-2 Description

The following brief description of the Ice, Cloud and land Elevation Satellite-2 (ICESat-2) observatory and Advanced Topographic Laser Altimeter System (ATLAS) instrument is provided to help users better understand the file naming conventions, internal structure of data files, and other details referenced by this user guide. The ATL13 data product is described in detail in the Ice, Cloud, and land Elevation Satellite-2 Project Algorithm Theoretical Basis Document (ATBD) for Inland Water Data Products (ATBD for ATL13 | V03).

The ATLAS instrument and ICESat-2 observatory utilize a photon-counting lidar and ancillary systems (GPS and star cameras) to measure the time a photon takes to travel from ATLAS to Earth and back again and to determine the photon's geodetic latitude and longitude. Laser pulses from ATLAS illuminate three left/right pairs of spots on the surface that as ICESat-2 orbits Earth trace out six ground tracks that are typically about 14 m wide. Each ground track is numbered according to the laser spot number that generates it, with ground track 1L (GT1L) on the far left and ground track 3R (GT3R) on the far right. Left/right spots within each pair are approximately 90 m apart in the across-track direction and 2.5 km in the along-track direction. The ATL13 data product is organized by ground track, with ground tracks 1L and 1R forming pair one, ground tracks 2L and 2R forming pair two, and ground tracks 3L and 3R forming pair three. Each pair also has a Pair Track—an imaginary line halfway between the actual location of the left and right beams (see figures 1 and 2). Pair tracks are approximately 3 km apart in the across-track direction.

The beams within each pair have different transmit energies—so-called weak and strong beams—with an energy ratio between them of approximately 1:4. The mapping between the strong and weak beams of ATLAS, and their relative position on the ground, depends on the orientation (yaw) of the ICESat-2 observatory, which is changed approximately twice per year to maximize solar illumination of the solar panels. The forward orientation corresponds to ATLAS traveling along the +x coordinate in the ATLAS instrument reference frame (see Figure 1). In this orientation, the weak beams lead the strong beams and a weak beam is on the left edge of the beam pattern. In the backward orientation, ATLAS travels along the -x coordinate, in the instrument reference frame, with the strong beams leading the weak beams and a strong beam on the left edge of the beam pattern (see Figure 2). The first yaw flip was performed on December 28, 2018, placing the spacecraft into the backward orientation. ATL08 reports the spacecraft orientation in the sc_orient parameter stored in the /orbit_info/ data group (see Section 1.2.4 Data Groups). In addition, the current spacecraft orientation, as well as a history of previous yaw flips, is available in the ICESat-2 Major Activities tracking document (.xlsx).

The Reference Ground Track (RGT) refers to the imaginary track on Earth at which a specified unit vector within the observatory is pointed. Onboard software aims the laser beams so that the RGT is always between ground tracks 2L and 2R (i.e. coincident with Pair Track 2). The ICESat-2 mission acquires data along 1,387 different RGTs. Each RGT is targeted in the polar regions once every 91 days (i.e. the satellite has a 91-day repeat cycle) to allow elevation changes to be detected. Cycle numbers track the number of 91-day periods that have elapsed since the ICESat-2 observatory entered the science orbit. RGTs are uniquely identified, for example in file names, by appending the two-digit cycle number (cc) to the RGT number, e.g. 0001cc to 1,387cc.

Under normal operating conditions, no data are collected along the RGT; however, during spacecraft slews, or off-pointing, some ground tracks may intersect the RGT. Off-pointing refers to a series of plans over the mid-latitudes that have been designed to facilitate a global ground and canopy height data product with approximately 2 km track spacing. Off-pointing began on 1 August 2019 with RGT 518, after the ATLAS/ICESat-2 Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions had been adequately resolved and the instrument had pointed directly at the reference ground track for a full 91 days (1,387 orbits).

Users should note that between 14 October 2018 and 30 March 2019 the spacecraft pointing control was not yet optimized. As such, ICESat-2 data acquired during that time do not lie along the nominal RGTs, but are offset at some distance from the RGTs. Although not along the RGT, the geolocation information for these data is not degraded.

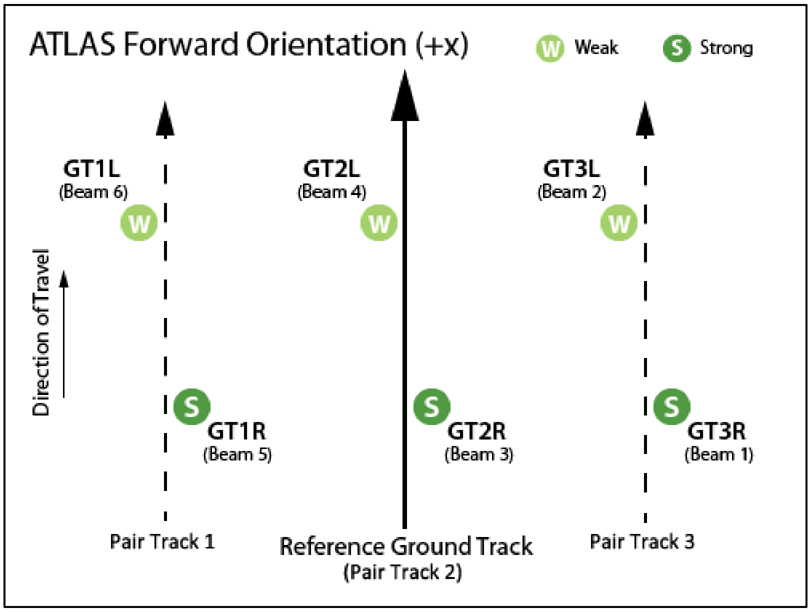

Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction.

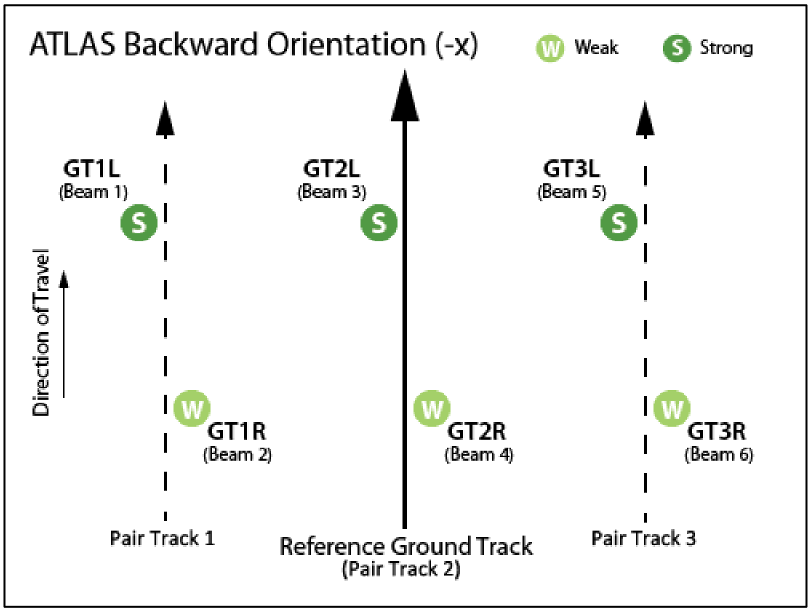

Figure 2. Spot and ground track (GT) naming convention with ATLAS oriented in the backward (instrument coordinate -x) direction.

NOTE: ICESat-2 reference ground tracks with dates and times can be downloaded as KMZ files from NASA's ICESat-2 | Technical Specs page, below the Orbit and Coverage table.

1.2.3 File Contents

Data files (granules) contain inland water body surface heights acquired during four of ATLAS's 1,387 orbits.

1.2.4 Data Groups

Within data files, similar variables such as science data, instrument parameters, altimetry data, and metadata are grouped together according to the HDF model. ATL13 data files contain the top-level groups shown in Figure 3:

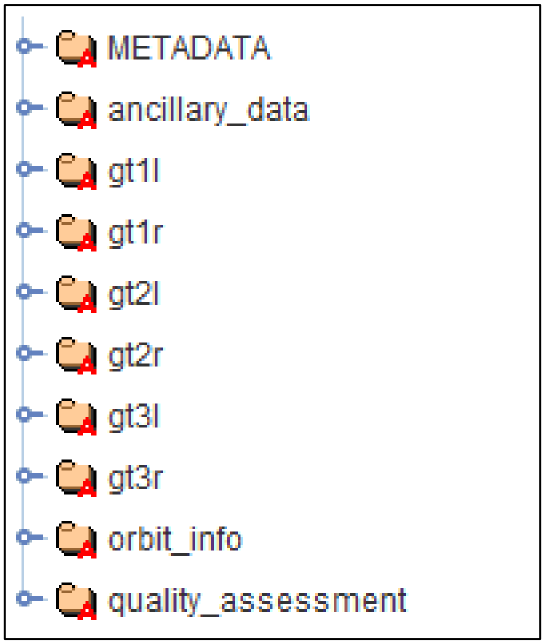

Figure 3. ATL13 data groups shown in HDFView.

The following sections summarize the structure and primary variables of interest in ATL13 data files. For a complete list of parameters, see the ATL13 Data Dictionary.

1.2.4.1 METADATA

ISO19115 structured summary metadata for the granule, including content that describes the required geospatial information.

1.2.4.2 ancillary_data

Information that is ancillary to the data product. This may include product and instrument characteristics and/or processing constants.

1.2.4.3 gt1l – gt3r

Six ground track groups (gt1l – gt3r) that contain the per-beam data parameters for the specified ATLAS ground track. Parameters of interest include:

- Water surface height (ht_water_surf) above the WGS 84 ellipsoid;
- Orthometric surface height (ht_ortho), i.e. height above the EGM2008 MSL;
- Geoid value at short segment reporting location (segment_geoid);
- Water body type (inland_water_body_type); size (inland_water_body_size); shape mask source (inland_water_body_source); and water body ID (inland_water_body_id). When concatenated, these four values uniquely identify each water body (See "4.7.1.2 | Water Body Reference Identification Scheme" in the ATBD for ATL13).
- Short segment length flag (qf_sseg_length);
- Mean latitude (sseg_mean_lat), longitude (sseg_mean_lon), and time (sseg_mean_time) of short segment signal qualified photons
- Short segment, along-track, water-body surface slope (segment_slope_trk_bdy)

The gt[x] groups also contain a variety of descriptive statistics. The complete contents of the gt[x] groups are listed in "Table 5-1 | ATL13 Inland Water Along Tract Output Parameters" in the ATBD for ATL13.

1.2.4.4 orbit_info

Orbit parameters that are constant for a granule, such as the RGT number and cycle and the spacecraft orientation (sc_orient).

1.2.4.5 quality_assessment

Quality assessment data for the granule as a whole, including a pass/fail flag and a failure reason indicator.

1.2.5 Naming Convention

Data files utilize the following naming convention:

Example:

- ATL13_20181013205512_02330101_002_01.h5
- ATL13_[yyyymmdd][hhmmss]_[ttttccss]_[vvv_rr].h5

The following table describes the file naming convention variables:

Table 1. File Naming Convention Variables and Descriptions

Variable	Description
ATL13	ATLAS/ICESat-2 L3A Inland Water Surface Height
yyyymmdd	Year, month, and day of data acquisition
hhmmss	Data acquisition start time, hour, minute, and second (UTC)
tttt	Four digit RGT number of the first of four tracks in the granule. The ICESat-2 mission has 1,387 RGTs, numbered from 0001 to 1387.
cc	Cycle Number. The cycle number tracks the number of 91-day periods that have elapsed since ICESat-2 entered the science orbit.
ss	Segment number. Not used for ATL13. Always 01.[1]
vvv_rr	Version and revision number.[2]

NOTE:

[1]Some ATLAS/ICESat-2 products (e.g. ATL03) are provided as files that span 1/14th of an orbit. As such, these products' file names specify a segment number that ranges from 01 to 14. Because ATL13 data files span four full orbits, the segment number is always set to 01.

[2]From time to time, NSIDC receives duplicate, reprocessed granules from our data provider. These granules have the same file name as the original (i.e. date, time, ground track, cycle, and segment number), but the revision number has been incremented. Although NSIDC deletes the superseded granule, the process can take several days. As such, if you encounter multiple granules with the same file name, please use the granule with the highest revision number.

Each data file has a corresponding XML file that contains additional file level metadata. XML metadata files have the same name as their corresponding .h5 file, but with .xml appended.

1.2.6 Browse File

Browse files are provided as HDF5 formatted files that contain images designed to quickly assess the location and quality of each granule's data. Browse images include water surface orthometric height (named "default1") and granule ground track location and coverage ("default2").

Browse files utilize the same naming convention as their corresponding data file, but with _BRW appended.

1.2.7 File Size

Files range from approximately 1 MB to 10 MB.

1.3 Spatial Information

1.3.1 Coverage

Spatial coverage spans approximately 88° N latitude to 88° S. Water surface height processing is constrained by an inland water mask (see Section 2.3.1 Water Masks).

1.3.2 Resolution

The ATLAS instrument transmits laser pulses at 10 kHz. At the nominal ICESat-2 orbit altitude of 500 km, this yields approximately one transmitted laser pulse every 0.7 meters along ground tracks. Note, however, that the number of photons that return to the telescope depends on surface reflectivity and cloud cover (which obscures ATLAS's view of Earth). As such, the spatial resolution of individual signal photons varies.

Inland water heights are processed in segments that contain a minimum of approximately 100 signal photons, to ensure the segment accurately characterizes the water surface. As such, the segments vary in length from approximately 30 m to 200 m (averaging about 100 m), depending on factors such as signal quality and water and atmospheric conditions.

1.3.3 Geolocation

Latitudes and longitudes refer to the WGS 84 coordinate system. Water surface heights are provided as both heights above the WGS 84 ellipsoid (ITRF2014 Reference Frame) and as heights above mean sea level (EGM2008). The following table contains details about WGS 84:

Table 2. Geolocation Details

Geographic coordinate system	WGS 84
Projected coordinate system	N/A
Longitude of true origin	Prime Meridian, Greenwich
Latitude of true origin	N/A
Scale factor at longitude of true origin	N/A
Datum	World Geodetic System 1984
Ellipsoid/spheroid	WGS 84
Geoid	EGM2008
Units	degrees
False easting	N/A
False northing	N/A

EPSG codes	4326 (WGS 84) 3855 (EGM2008)
PROJ4 string	+proj=longlat +datum=WGS84 +no_defs
Reference	https://epsg.io/4326 (WGS 84) https://epsg.io/3855 (EGM2008)

For information about ITRF2014, see the International Terrestrial Reference Frame | ITRF2014 webpage.

1.4 Temporal Information

1.4.1 Coverage

13 October 2018 to 11 November 2020

1.4.2 Resolution

Repeat observations for any given water body depend on its size and geographic location. The frequency at which ATLAS/ICESat-2 crosses inland water bodies depends on how often the spacecraft's orbital pattern intersects with the water body mask. For high latitude, polar regions (approximately ±65°), the mission requirements manadate repeat observations every 91 days along the precisely established reference tracks (i.e. the satellite has a 91 day repeat cycle). However, starting with cycle 04 (28 June 2019) ATLAS/ICESat-2 is slated to begin conducting a systematic off-pointing scenario at lower latitudes that is designed to achieve approximately 2 km global spacing after two years of data acquisition.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

The ATL13 product is derived primarily from geolocated, time-tagged photon heights and other parameters passed to it from the ATLAS/ICESat-2 L2A Global Geolocated Photon Data (ATL03) product. The following figure illustrates the family of ICESat-2 data products and the connections between them:

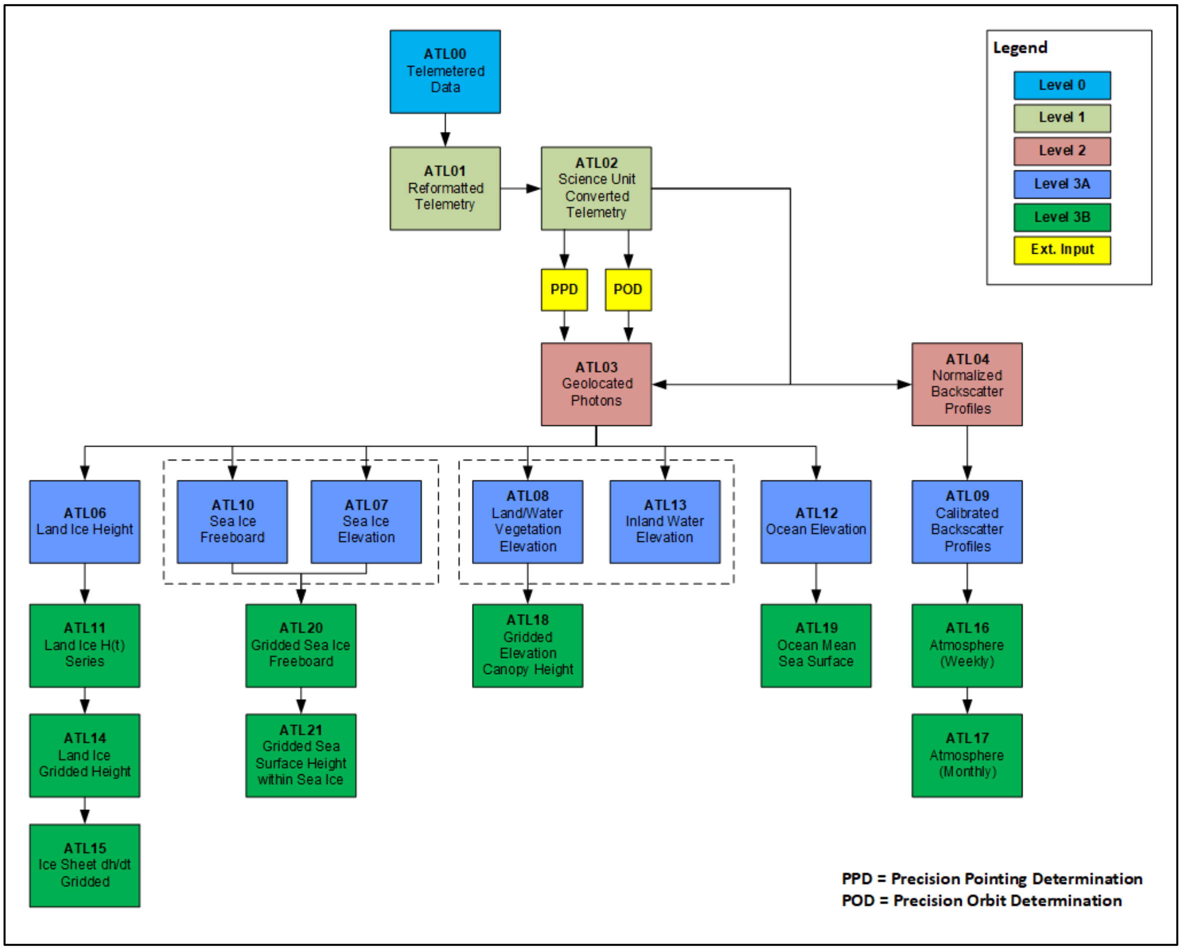

Figure 4. ICESat-2 data processing flow. The ATL01 algorithm reformats and unpacks the Level 0 data and converts it into engineering units. ATL02 processing converts the ATL01 data to science units and applies instrument corrections. The Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions compute the pointing vector and position of the ICESat-2 observatory as a function of time. ATL03 acts as the bridge between the lower level, instrumentation-specific products and the higher-level, surface-specific products.

2.2 Acquisition

Inputs from ATL03 product include precise latitude, longitude, and height for every received photon, plus applied geophysical corrections such as Earth tides and atmospheric delays. Each photon is also classified as signal or background and by surface type (land ice, sea ice, land, ocean, and inland water).

> NOTE: The following sections summarize the approach used to generate the ATL13 product. For a complete description of the theory and algorithm, consult the ATBD for ATL13.

2.3 Processing

2.3.1 Water Masks

Water masks help organize the inland water data and constrain processing to only those land and coastal regions that possess water bodies. ATL13 relies on three types of hydrologic masks:

- ATL03 Inland Water Mask (applied to input data)
- ATL13 Regional Basin Mask
- ATL13 Inland Water Body Shape Mask

The **ATL03 Inland Water Mask**, shown in Figure 5, improves computational efficiency by allowing the ATL13 algorithm to process only ATLAS observations that have been flagged by ATL03 as inland water (Section 3.4, ATBD for ATL13).

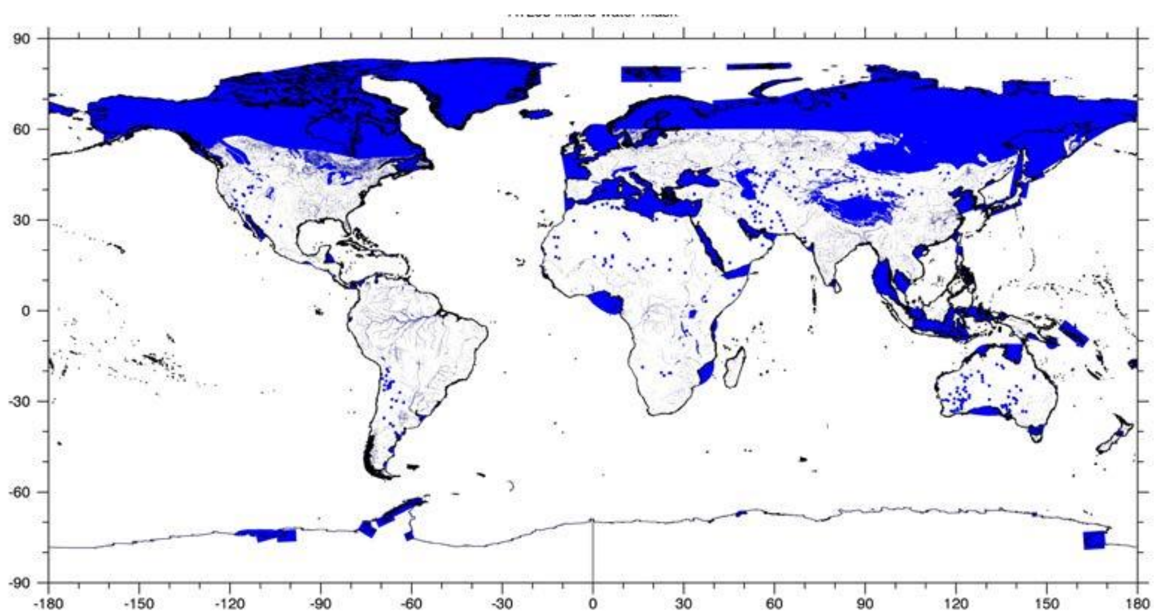

Figure 5. ATL03 Inland Water Mask.Observations that fall within shaded areas (blue) are flagged as water bodies.

This 0.1 km^2, gridded mask was developed from a number of coastline and inland water databases including the Global Self-consistent, Hierarchical, High-resolution Geography (GSHHG) coastlines database and various lake shapefiles, including ephemeral lakes, permafrost extent, and custom shapes created to close larger bays in locations not otherwise addressed.

The **ATL13 Regional Basin Mask** comprises polygons that represent principally the outline of entire large river basins plus some adjacent intervening area. Each polygon contains all the lakes and rivers within that river basin and organizes in a logical manner the ATLAS data used to produce the hydrologic products (Section 3.5, ATBD for ATL13).

The **ATL13 Inland Water Body Shape Mask** identifiies ICESat-2 crossings over individual water bodies. It was designed to delineate the shape and spatial distribution of contiguous individual water bodies, such as lakes and rivers, and is applied as a shape-file—unlike the gridded ATL03 mask flag described above. As implemented in this version of ATL13, the shape mask consists of polygons that each represent an entire single lake, reservoir, estuary, bay, or coastal buffer with an approximately 100 m buffer over land to clearly distinguish the land/water interface. Each water body is identified by a unique number, latitude and longitude, and, if available, local name (Section 3.6, ATBD for ATL13).

2.3.2 Surface Height Algorithm

The number of inland water surface signal photons ranges between 0.5 and several photons per meter, under normal conditions, to more than 25 photons per meter for highly specular situations. The goal of ATL13 is to estimate the mean water surface height in short, statistically representative segments (~100 photons), for each ATLAS beam that crosses a water body in the along-track direction. Thus computing inland water heights requires distances of at least 100 m, depending on atmospheric, solar, and water conditions. In addition, although the large majority of the signal photons that return to ATLAS from a given water body are reflected from the surface, typically as many as several percent comprise subsurface backscatter. As such, prior to computing the ~100 photon short segments the algorithm analyzes longer segments (1 to 3 km), which contain a sufficient number of subsurface photons to estimate the volume scattering parameters. Thus the ATL13 product combines physical and statistical modeling approaches to characterize key physical processes related to open water surface dynamics and light propagation and retrieve inland water heights from (primarily) ATL03 data.

In brief, the algorithm: 1) identifies the beginning and ending edges where individual ATLAS beams intersect a contiguous water body; 2) models the reflectance components that contribute to the integrated signal return from the water body; 3) analyzes models of the surface water height statistical distributions, subsurface volume attenuation, and their relation to the distribution of the signal photons from water surface facets; 4) removes background photons to extract the true representation of water reflectance and height; 5) deconvolves the ATLAS instrument response function from the observations; 6) computes along-track statistics, including: surface water height; subsurface attenuation; coarse-resolution water depth; significant wave height; the mean, maximum along-track water surface slope and azimuth from the two adjacent strong beams; and 7) evaluates the accuracy and quality of the measurement.

The following sections outline the major components used to estimate inland water heights in ATL13. For additional details, consult the referenced sections in the ATBD for ATL13. The algorithm implementation is described in Section 5.0.

2.3.2.1 Inland Water Backscatter

"Section 4.2 | Satellite Inland Water Backscatter Model" in the ATBD for ATL13 describes the approach used to model inland water backscatter. It includes sections which discuss: the water surface specular model (4.2.1); the water surface foam model (4.2.2); the volume scattering model (4.2.3); bottom reflectance (4.2.4); the relative magnitude of anticipated returns (4.2.5); and required atmospheric and meteorological inputs (4.2.6).

2.3.2.2 Water Surface Height

"Section 4.3 | Water Surface Height Model" discusses the approach used to differentiate signal photons associated with water height, including subsections that address: removing signal photons not associated with water surface height (4.3.1); estimating the background and signal to background noise ratio (4.3.2); estimating water surface height and along-track slope (4.3.3); and estimating the slope variance (4.3.4).

2.3.2.3 ATLAS Instrument Response Function

"Section 4.4 | Instrument Response Function (Transmitted Pulse Shape)" and "Section 4.5 | Deconvolution of Instrument Response from Lidar Returns" describe the approach used to deconvolve the instrument response function (or histogram) from the observed histogram to extract the actual water response histogram.

2.4 Quality, Errors, and Limitations

Data quality in this product depends largely on the precision of the georeferenced photons input from ATL03 and associated products evaluated prior to use by the ATL13 algorithm. The overall ensemble error per 100 inland water photons is estimated to be 6.1 cm. This calculation is detailed in "Section 4.9.1 | ICESat-2 Precision" in the ATBD for ATL13.

The Inland Water Team will be evaluating error in this product as more data are acquired. "Section 4.9.2 | Data Product Evaluation" in the ATBD describes the Inland Water Team's initial plan to assess ATL13 data quality in conjunction with relevant U.S. agencies, organizations, and university researchers.

3 VERSION HISTORY

Version 3 (May 2020)

Changes for this version include:

- The water body shape file has been updated to include improved river shapes (see Section 3.6, ATBD for ATL13).
- The first photon bias (FPB) correction has been implemented to calculate the apparent width of the full-width at half-max (FWHX) standard deviation of the ATL13 surface (see "Section 4.7.3.6 | First photon bias correction" in the ATBD for ATL13), the apparent strength, and the average detector time. This bug fix improves surface retrievals, especially for highly specular water surfaces.
- Implemented an estimate of short segment wind speed from ATL09 input wind vector components at 10m, interpolated to short segment index photon times (gt[x]/met_wind10_atl09); and derived standard deviation of water surface at the long segment rate (gt[x]/met_wind10_atl13).
- Using a previously identified water body bottom, implemented a minimum height for the range over which to perform the subsurface deconvolution and the bottom height of the vertical profile for long segments. This improves subsurface attenuation when the bottom is detected.
- The threshold procedure that tests photon counts within short-segment histogram multimode bins against sseg_mode_cnt_test, to determine whether to include/exclude from the segment, has been updated to use the standard deviation of signal photon heights per shot segment (sseg_stdev). This bug fix addresses bias due to the removal of ATL13 outputs in the case of large wave heights.
- The value of ancillary_data/inland_water/geoseg_edge_buffer is now selected based on the type and size of a given water body. This change fixes a bug in previous versions and improves the identification of shorelines (see "4.3.1 | Photons contributing to the water surface height," ATBD for ATL13).
- Added a parameter in the water surface height computation that incorporates the maximum available geolocation segments from ATL03, as indicated by geoseg_edge_buffer (default = 5), that lie outside both lake mask edge crossings (added for use in future products currently under development).
- Changed the sign for electromagnetic bias (H_bias_EM). This fixes a bug in previous versions.
- The expression for orthometric water surface height (equations 4.23 and 4.24, ATBD for ATL13) and depth from the mean water surface to the detected bottom have been updated to exclude H_bias_EM, when it is designated as invalid, and H_bias_fit is designated as valid. This update improves this special case.
- Implemented a new scheme that removes misidentified water surfaces due to near-shore influences. After testing that a valid number of short segments have passed all other anomaly testing (valid_sseg_count), and determining the maximum length of a short segment that can be marked as anomalous due to shore buffering (shore_buff_sseg_length), the number of short segments to be designated as anomalous, due to near-shore influences (shore_buffer), is implemented as a 9x9 matrix that depends on water body type and size.
- Cloud confidence flag parameters gt[x]/cloud_flag_atm_atl09, gt[x]/cloud_flag_asr_atl09, and gt[x]/layer_flag_atl09 are now retrieved from the ATL09 product and reported on ATL13 at the short segment rate using nearest neighbor interpolation. This was added to help analyze and better understand short-segment data products.
- Implemented surface (skin) temperature (gt[x]/met_ts_atl09) and NOAA snow/ice flag (gt[x]/snow_ice_atl09) at the short segment rate, derived by interpolation/resampling

ATL09 inputs (met_ts and snow_ice) at the 1 Hz and 25 Hz rates. These parameters were added to help analyze and improve overall understanding of short-segment data products.

- Added six water body transect parameters to gt[x]/ (transect_id; sseg_start_lat; sseg_start_lon; sseg_end_lat; sseg_end_lon; and segment_azimuth) which will be used by future inland water body products, currently in development.

4 CONTACTS AND ACKNOWLEDGMENTS

Michael F. Jasinski
NASA Goddard Space Flight Center
Mail Code: 617
Greenbelt, MD 20771

Jeremy D. Stoll
NASA Goddard Space Flight Center
Mail Code: 617
Greenbelt, MD 20771

David Hancock
NASA Goddard Space Flight Center
Mail Code: 610.W
Wallops , VA 23337

John Robbins
NASA Goddard Space Flight Center
Mail Code: 615
Greenbelt, MD 20771

Jyothi Nattala
NASA Goddard Space Flight Center
Mail Code: 615
Greenbelt, MD 20771

Jamie Morison
Polar Science Center
Applied Physics Laboratory
University of Washington
Seattle, WA 98105

Benjamin M. Jones
Water and Environmental Research Center

University of Alaska Fairbanks
Fairbanks, AK 99775

Michael E. Ondrusek
Center for Satellite Applications and Research
National Environmental Satellite, Data, and Information Service
National Oceanic and Atmospheric Administration
College Park, MD 20740

Tamlin M. Pavelsky
Department of Geological Sciences
University of North Carolina at Chapel Hill
Chapel Hill, NC 27599

Christopher Parrish
College of Engineering
Oregon State University
Corvallis, OR 97331

5 DOCUMENT INFORMATION

5.1 Publication Date

28 May 2019

5.2 Date Last Updated

25 January 2022